Constraints and Requirements in Model Validation illustrated through Development and Characterization of a Component Failure Model

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The term "Model Validation" is a generic umbrella term encompassing many different model validation aspects and activities at various levels of modeling, from the isolated constituitive modeling level to integration in system-level simulations where validation is important for informed decision making. Over this modeling spectrum, model validation may mean different things and be measured against very different scales of required or desired accuracy. This paper will survey several different conceptions of Model Validation for their versatility and applicability over this spectrum. A pragmatic approach to model validation methodology from a model development and characterization standpoint will be developed and applied that grapples with the real-world difficulties of:

a) sparse data;

b) uncertainty in the data from sources that involve unit-to-unit variabilities, test-to-test variabilities, and diagnostic measurement resolution limits;

c) modeling error and uncertainty induced by numerical models, such as iterative, time-discretization, and space-discretization errors;

d) integration of what we learn in isolation into assertions at the system level, given ignored or approximated interaction and correlation effects when a complex system is separated into elements and model validation is performed on the separate uncoupled elements;

e) correctly propagating requirements downward from the system level to relevant operational space requirements on testing and experiments at lower separated levels;

f) in many cases being required to measure different variables in lower-level experiments than can be straightforwardly employed when trying to propagate validation information upward -this uncertainty information must many times be re-parameterized in terms of more natural "linking variables" for such upward propagation.

The proposed Model Validation methodology will be applied to a failure model for thermally-induced failure of a safety system component that has aspects of all the above elements. Upwards of 70 tests ([1]) have been performed on the component to characterize its thermal failure. Reanalysis of the data in [2] using a finite element thermal model helped produce a much tighter characterization of failure temperatures, but limited Model Validation concepts were applied in the

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analysis. The present effort to be reported in this paper applies more sophisticated Model Validation concepts to bias-correct and reanalyze the data, and to develop and improve/calibrate the failure model, and then appropriately characterize the remaining uncertainty. The application of validation concepts to this problem is made difficult by several obstacles frequently encountered in real applications, such as:

- significant uncertainty in computed results due to significant numerical under-convergence in the simulations
- significant confidence-interval uncertainties from limited experimental sampling
- difficulty of deconvolving unit-to-unit variabilities from test-to-test setup variabilities because the tests are destructive (the units can't be tested multiple times to quantify setup variabilities)
- large epistemic uncertainties exist in bias corrections to the experimental data to adjust for *e.g.* thermocouple temperature reading errors

REFERENCES

[1] Edwards, L.R., K.C. Chen, R.V. Baron, C.F. King, "Characterization of the SA2962 Capacitor in Abnormal Thermal Environments," Sandia National Laboratories report SAND99-2332 printed Sept. 1999.

[2] Sherman, M.P., J.F. Dempsey, V.J. Romero, M. Pilch, R.C. Dykhuizen, "Thermal Modeling and Failure Characterization of the SA2962 Capacitor," Sandia National Laboratories report in preparation.